DEVICE FOR THE RECONDENSATION, BY MEANS OF A CRYOGENERATOR, OF LOW-BOILING GASES EVAPORATING FROM A LIQUID GAS CONTAINER

This is a Continuation-In-Part application of international application PCT/EP02/07406 filed 07/04/02 and claiming the priority of German application 101 37 552.2 filed 08/01/01.

BACKGROUND OF THE INVENTION

The invention relates to a device for the re-condensation of low-boiling gases evaporating from a liquid gas container by means of a cryo-generator. With such a device for example a superconductive magnet which is cooled by immersion into liquid helium can be operated over an extended period by re-condensation of the helium evaporated. The device is a small refrigeration apparatus, a so-called cryo-cooler. In a similar way, such a device is used in connection with a superconductive magnet of high-temperature superconductive material which is cooled by immersion into liquid nitrogen.

Below the present state of the art is described shortly (see also Fig. 4):

The cryo-container 1 consists of an inner container 2, which is filled with the low-boiling liquid gas, for example, liquid helium, up to a level 7. The superconductive apparatus, typically a magnetic coil 5 including the power supply lines 6a, 6b is immersed into the liquid gas. The helium evaporating as a result of the heat supplied to the container 2 is conducted, by way of a narrow tube 8, to the ambient or rather to a collecting container. For reducing the heat in-

flux, the helium container 2 is surrounded by an enclosure 3 and the space between the inner container 2 and the outer enclosure 3 is evacuated. For further reducing the heat influx, a radiation shield 4 is arranged in the vacuum space between the container 2 and the enclosure 3. The radiation shield 4 is cooled by the helium gas by way of a contact ring 10 disposed on the tube 8. On one hand, the tube 8 should be as narrow as possible in order to reduce the heat influx but, on the other hand, if, accidentally, the magnet becomes suddenly normally conductive, the tube 8 should have a sufficiently large cross-section to permit the discharge of the additional gas generated in order avoid in that case an excessive pressure increase in the container 2.

When the helium level has dropped below a certain height the helium must be replenished from a transport container. This requires substantial efforts and expenditures.

There are small cooling devices (cryo-generators) by which the helium evaporating from the helium bath can again be liquefied and returned directly to the cryo-container. Some of these devices have two- or several stages and provide sufficient cooling energy for the cooling of radiation shields. The most important embodiments of such cryo-generators are presently the pulse tube cooler and the Gifford-McMahon cooler.

As far as this is possible with such low temperature cooling apparatus such a cryo-generator should be easy to handle, uncomplicated in its operation and easy to service. The low temperature-boiling gases used in these cooling apparatus are helium, He, Hydrogen H_2; Neon, Ne; nitrogen, N_2 which are also used in the superconductor technology as coolants.

A cryo-generator consists basically of cooling equipment with a so-called cold head. This cold head is mounted outside

onto the apparatus and extends into the tube 8 down to the container 3 for the liquid gas. There, the cold area 26 is exposed to the liquid level 7 of the liquid gas. The single-stage cooling apparatus is so designed and installed that it can be removed and re-installed without heating the liquid gas. The cold head comprises a regenerator 21 and a pulse tube 23 with a heat exchanger 25 disposed therebetween. The heat exchanger 25 is embedded in the cold area 26, which is exposed toward the liquid gas bath.

The components regenerator 21, pulse tube 23 are surrounded each by a thermally isolating enclosure/heat shield (20, 30, 31, 32) in order to prevent thermal coupling to the outside or at least to maintain it within acceptable limits.

The cooling apparatus that is the cold head may be of different design, but it includes generally at least two stages. It also extends into the tubular neck 8 and its last stage cold area 28 is disposed above the liquid gas bath. Also, such a multistage cold head can be removed and re-installed without heating the liquid gas bath. Each stage of the cold head consists of a regenerator 21, and, respectively, 22 and a pulse tube 23 and, respectively, 24, with a heat exchanger 25 and, respectively, 27 disposed therebetween. Each heat exchanger is contained in a cold area 26 or, respectively, 28. The cold area of the last stage extends with its exposed surface into the cold vapor space of the liquid gas container 2. The components, the regenerator 21 and respectively, 22, the pulse tube 23 and respectively, 24 of the respective stage are, like in the single stage embodiment, each surrounded by a thermally insulating tube 29, 30, 31, 32. All the cold areas 26, except for the last one, are disposed in the direction toward the next following stage co-axially opposite a heat transfer ring 10, which is disposed at the respec-

tive location in the tubular neck 8 in good heat transfer relationship. The respective cold head area 26 extends in an axially movable manner, with a small equidistant gap around the circumference, into the associated heat transfer ring 10, without coming into contact therewith at any point. In this way, there is always a gas passage open from the vapor space above the liquid gas bath to the flange of the cold head. The multistage cooling apparatus extending into the tubular neck 8, which is mounted onto the flange cover 33 that is bolted onto a connector flange 9 of the corner wall 3, can expand axially as a result of thermal effects without restrictions.

It is the object of the present invention to provide an improved device for the re-condensation of low boiling gases evaporating in a liquid gas container.

SUMMARY OF THE INVENTION

In a device for the re-condensation of low-boiling gases evaporating from a liquid gas container having a tubular neck in which a cold head of a cryo-generator is supported, the cold head includes a pulse tube with a heat exchanger and a cold area having an annular projection extending into an annular recess formed in a heat transfer ring mounted in the tubular neck in closely spaced relationship with the walls of the annular recess so as to provide a gas passage therethrough and permitting relative axial movement between the cold head and the liquid gas container.

Preferably, the thermally isolating shield 20, 30, 31, 32 consists of a layer which is disposed on the respective component and consists of a material which has a low heat conductivity and which prevents or severely limits axial and radial heat transfer.

Thermal insulation is provided by an evacuated space extending from end to end of an envelope. To this end, the respective component is surrounded by a thin-walled cylindrical tube with low heat conductivity which, because of its shape or a support structure, remains so stiff that the exterior pressure - that is generally the ambient pressure, in fault situations such as sudden transition of the immersed coil from a superconductive to a normally conductive state generating excess pressure - cannot move the cylindrical tube into contact with the envelope wall over an extended area. Preferably, also the support structures which stiffen the outer wall of the vacuum space consist of a material with low heat conductivity. The support structure may include a rope wound helically around the component from the top to the bottom or vice versa. In place of such a continuous rope, rope sections may be provided on the circumference of the component which are not in contact with one another. Other measures known from the state of the art of insulation engineering may also be used if applicable.

In another effective way of providing a vacuum chamber, the outside wall of the vacuum chamber is a thin-walled corrugated tube whose inner open diameter is slightly larger than the component disposed within so that, if contacts are formed, they are established only as short line contacts with the outer wall of the component. Such a chamber may also be formed by a thin-walled tube which has projections or line-like reinforcements so that contacts can be provided only in spots or over short lines.

The outer wall of the vacuum chamber may furthermore consist of a thin-walled corrugated tube which has an inner open width which is also slightly larger than that of the one which is surrounded thereby and is held in spaced relationship by

rod elements which helically surround the component or by axial rods disposed in circumferentially spaced relationship on the component.

For a low-resistance gas flow particularly during a fault each of the cold areas 26 is provided with at least one bore 37a or more bores 37a uniformly distributed over the circumference.

The advantages of the device according to the invention obtained as a result of the design features disclosed will be described below with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a device for the re-condensation of low boiling gases with a cryo-generator including two pulse tube coolers,

Fig. 2a shows a rope wound helically around a pulse tube cooler tube for ensuring a certain spacing,

Fig. 2b shows the pulse tube disposed in a corrugated hose for ensuring a certain spacing,

Fig. 3 shows the arrangement with two McMahon coolers, and

Fig. 4 shows the diagram of a cryostat.

DESCRIPTION OF THE ARRANGEMENTS OF THE INVENTION AND THE ADVANTAGES THEREOF

Fig. 1 shows schematically the construction of the cold head of the two-stage pulse tube cooler and its installation in a cryostat. The pulse tube cooler and its components are only shown to the extent they are needed for an understanding of the invention.

The two-stage cooler consists of the regenerator 21 with a connecting line 37 to a compressor which is not shown and

which supplies the pulsating gas flow. The pressure varies typically between about 10 bar and 25 bar. At the other end of the regenerator, the gas flow is divided so that a first partial flow is admitted through the first heat exchanger 25 to the first pulse tube 23. At the opposite end thereof, a second gas flow is admitted by way of the connection 34. With suitably adjusted values and a time shift of these gas flows a cooling effect is achieved in the area of the heat exchanger 25 providing for a refrigeration output. With this refrigeration output, the radiation shield 4 is cooled down to a first temperature level, which is already substantially below the ambient temperature. For the thermal coupling of the radiation shield 4 to the location of the refrigeration output the heat transfer device 26 comprises a structure with good heat conductivity, the so-called first cold area 26. At the side adjacent the heat transfer ring 10 which is connected to the tubular neck 8, the first cold area 26 has a circumferentially toothed structure and the heat transfer ring 10 has a complementary structure. This toothed structure is so designed that at the interface areas which extend in the figure vertically between the cold area 26 and the transfer ring 10 a very narrow gap remains which is filled with the gas evaporating in the container. On the other hand, the tooth engagement is such that a displacement in the vertical direction is possible. In this way, on one hand, a good thermal coupling is achieved and, on the other hand, relative displacement as it occurs for example with different thermal expansions and contractions, is possible.

Furthermore, the cold head can be removed and reinstalled when necessary without heating the cryostat.

The second partial flow of gas out of the first regenerator 21, which has an intermediate temperature, is conducted,

by way of the second heat transfer structure 27, into the second pulse tube 24 to which, by way of the gas conduit 36 at the upper end thereof, also a pulsating gas flow is supplied. In this way, in the area of the second heat transfer structure 27, the temperature is further reduced. Such coolers are in accordance with the state of the art so constructed that at the first stage a first temperature reduction in the range of 30°K and 100° and in the second stage a cooling energy with a much smaller temperature reduction in a temperature range of 5°K which is available for the condensation of helium is available. If the second heat exchanger 27 is embedded into the second cold area 28, which is a second heat conductive structure also with good heat conductivity and a large surface area on the side of the evaporating helium, the helium evaporating in the container 2 can be condensed and it can return to the bath disposed below.

Because of the method of operation of the cooler with a pulsating gas stream, the temperature varies slightly in each operating cycle at the surfaces subjected to the internal pressure. In the pulse tubes 23 and 24, this effect is particularly pronounced. With the temperature change at the side adjacent the evaporating helium a locally limited expansion of this gas occurs. This however, results in a movement of the gas in the whole container neck formed by the tubes 8a and 8b. As a result, there is a heat flow from the warm upper support flange 33 to the cold gas space 7, which is undesirable. There is furthermore an additional effect, which results from the different temperature distributions in the regenerators and the pulse tubes. As a result, these components may have different temperatures at the same level. This unavoidably results in a natural convection, which may also cause a detrimental heat transport.

Both effects are avoided if both regenerators 21, 22 and both pulse tubes 23, 24 have thermally insulated walls 29 to 32. The pulse tubes 23, 24 can be insulated by enclosing them in a layer of plastic which has a low heat conductivity or by providing an evacuated intermediate space that is a vacuum chamber. The numeral 30 designates the thermally insulating tube 29 surrounding the first regenerator, 29 designates the tube surrounding the second regenerator and 32 the tube surrounding the second pulse tube. It is however a disadvantage that through the wall of such a thermally insulating tube an additional heat flow to the respective cold end is established. In order to reduce this effect, the insulating tube must be as thin-walled as possible. However, if the wall is too thin, the tube may be bulged inwardly because of the external pressure effective thereon. The measures schematically shown in Figs. 2a and 2b help to avoid such bulging. Fig. 2a shows an example of such a component with the larger diameter, that is for the regenerator 21, wherein the tube 30 is provided with a support structure disposed on the inner tube 21a for stabilizing the tube. A second solution is shown in Fig. 2b. In this case, the thin-walled tube is in the form of a corrugated tube. If the open width of this corrugated tube is slightly greater than the outer diameter of the inner tube, only point-like contacts with negligible heat transfer bridges can form. These tubes may be permanently sealed or they may be connected to communication lines leading to a vacuum pump.

Under normal operating conditions, the helium gas assumes within the tubular neck 8a and 8b a stationary temperature distribution without internal connection and the connecting line 37 is closed. Only when the pressure in the gas space exceeds a predetermined value because of a fault, the exhaust gas line 37 is opened for example by way of a pressure relief

valve. If it is necessary to release a large amount of gas, the body 26 at the first cold area may be provided with bores 37a which facilitate the discharge of gases from the lower neck part with the surrounding wall 8b into the part with the surrounding wall 8a.

Fig. 3 shows schematically the important components of the Gifford McMahon cooler for helium re-condensation, specifically the analog solution for a two stage Gifford McMahon cooler. The first stage is formed by a circular structure 41. Its lower front end surface forms the first cold area 26. The following second cylinder 43 with smaller diameter forms the second stage. The pressure pulsations in the interior of these cylinders 41, 43 and the movement of the regenerators result in temperature changes at the outer walls. To avoid the undesirable heat flow caused thereby the wall surfaces of both cylinders should be thermally insulated. In the representation of Fig. 3, a corrugated tube structure 42, 44 is shown for that purpose. The other solutions described above can also be used in connection with the Gifford McMahon cooler.